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Assessment of technical and economical viability for large-scale conversion of single family residential buildings into zero energy buildings in Brazil: Climatic and cultural considerations

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HIGHLIGHTS

- Critique on super insolated buildings as a good solution for hot climates.
- PV parity already reached in some parts of Brazil.
- Proposal for a zero energy building definition for Brazil.
- Critique of the source metric for energy balance in zero energy buildings.
- Average roof area in Brazil enough for PV array to meet average energy consumption.

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ABSTRACT

This paper addresses the viability of converting single-family residential buildings in Brazil into zero energy buildings (ZEBs). The European Union and the United States aim ZEBs implementation to address 'peak oil' and environmental concerns. However, literature shows no agreement on a consensual definition of ZEB. Seeking a Brazilian ZEB definition, this paper addresses *PassivHaus* and thermal comfort standards for hot climates, source metrics for ZEB, Brazil′s energy mix, residential energy end uses and Brazilian legal framework for residential photovoltaic (PV) generation. Internal Rate of Return for PV systems in two Brazilian cities is calculated under various scenarios. It shows grid parity was reached from April 2012 to November 2012 assuming residential electric tariffs of that period and the financial conditions given by the Brazilian government for the construction of new dams in the Amazon and the lowest rates offered by Brazilian banks to private individuals. Governmental decision to lower electric residential tariffs in November 2012 reduced the scope of grid parity. Later revocation of a tax exemption in April 2013 ended grid parity in Brazil. It concludes, conversely to developed countries, it is the volatile Brazilian energy policy, instead of economical barriers, the main obstacle for ZEB viability in Brazil.

1. Introduction

1.1. General political context

Zero energy buildings are planned to become mandatory in the near future. The European Union has ruled it mandatory that new buildings be ZEBs from 2020 (European Parliament, 2011). Ireland has anticipated its deadline for 2013 while France, Germany and Hungary aim for ZEB in 2020. Holland is considering implementing this measure by 2020, while Finland and Norway are aiming for *PassivHaus* mandatory compliance, a step towards ZEB, in 2015 and 2017, respectively, according to the European Council For An Energy Efficient Economy (2011). The United Kingdom has set 2016 as its deadline for residential ZEBs (Department For Communities And Local Government, 2011). The US State of California aims to make it mandatory that new residential and commercial buildings are zero net energy by 2020 and 2025, respectively (California Legislature, 2009). In Denmark it has been mandatory for new buildings to be energy positive since 2010, according to Laustsen (2011). As a consequence, the literature on this subject includes reviews of initiatives, intentions and proposals for ZEB promotion (Charron, 2005; Kolokotsa et al., 2011), reports on the design process and ZEB strategies (Barnes et al., 2008; Leckner and Zmeureanu, 2011; Newell and Newell, 2010; Sherwin et al., 2010; Wang et al., 2009a, 2009b; Zhu et al.,2009a, 2009b), proposals for ZEB communities (Bağci, 2009; Carlisle et al., 2009), post occupancy of ZEB

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(Ferrante and Cascella, 2011; Hoque, 2010; Miller and Buys, 2011; Rosta et al., 2008; Wilke, 2009) and the actual definition of ZEB (Goldstein et al., 2010; Hernandez and Kenny, 2010; Marszal et al., 2011; Mlecnik, 2011; Pogharian, 2008; Sartori et al., 2011; Srinivasan et al., 2012; Torcellini and Crawley, 2006; Torcellini et al., 2006).

The above-mentioned policies arise from both energy and environmental concerns. The nearing of the 'peak oil' point has led to higher prices for fossil fuels and threatens the security of energy supply. Climate change mitigation policies reinforce the need for the widespread adoption of ZEB. Buildings consume 40% the world's primary energy, making it the number one sector in terms of energy consumption (International Energy Agency; Organisation for Economic Co-operation and Development, 2009). Thus, it is a prime target of energy policies dealing with energy mix transition.

1.2. Research questions

This paper proposes to answer two questions. The first question is: can the average Brazilian single family residential building be converted to a zero energy building (ZEB) considering average roof space available for PV generation and average energy consumption? The second question arises from the climatic, economical and legal differences that Brazil displays when compared with developed countries. Brazil is a mostly tropical country with a sizable equatorial area. Heat is the main cause of thermal discomfort conversely of what happens in EU and USA. Brazil has larger average PV generation potential than most EU countries. Notwithstanding the recent economical growth in Brazil and the reduction in economic inequality in the country, Brazil's average 10,816 USD of GDP per capita still lags behind most developed countries by 50 to 75%. Brazil is still one of the countries with the largest income inequality in the world. Additionally, residential electricity tariffs in Brazil are higher than those of the developed world. As such, can Brazil import the same ZEB strategies used in developed countries or must it create its own?

1.3. General ZEB definition

A ZEB is generally defined as a building provided with its own renewable energy system that generates as much energy as it consumes on a net annual basis. A ZEB is generally assumed to be connected to the utility grid and thus conceptually different from off-grid buildings. This distinction has far reaching effects. A grid-connected building allows an energy trade between the ZEB and utility grid. This trade allows ZEB to use the utility grid as an infinite capacity battery to draw power when needed. This option provides a safety net for the fluctuating nature of renewable energy generation, which is subject to variable weather conditions.[1] The utility grid also profits from energy exported by ZEBs when its generation surpasses its consumption.

Nevertheless, at the moment there is no clear and consensual definition of a ZEB. In fact, one of the aims of the joint IEA SHC Task40/ECBCS Annex52, focused on ZEB, is to create a clear and internationally accepted definition for a ZEB (Voss et al., 2009). The difficulties in reaching an agreement lead to some recent papers that do not propose a single universal ZEB definition. Instead they aim to present a framework that enables to compare the different ZEB definitions (Marszal et al., 2011; Sartori et al., 2011)[2]. The lack of consensual definition explains the array of alternative names for ZEBs which include zero carbon buildings and EQuilibrium buildings (Canada Mortgage And Housing Corporation, 2011).

Torcellini et al. (2006) wrote a paper alerting to the growing different definitions for ZEB. The authors found at least four different definitions for ZEB in the literature. These different definitions stemmed from distinct understanding over the meanings and limits of energy, renewable generation and energy consumption.

Since Torcellini et al. (2006), the scope of ZEB definitions has increased. Hernandez and Kenny (2010) propose the inclusion of the construction energy of the building in the energy balance. Goldstein et al. (2010) proposed the inclusion of commute transport energy from users to and from the building. Pogharian (2008) goes a step further proposing to account in the energy balance the energy embodied in the production of the food consumed by the building's users.

Torcellini et al. (2006), started to organize a framework to allow comparison of the different definitions. Some recent papers expanded such framework (Marszal et al., 2011; Sartori et al., 2011). Table 1 sums up the main issues mapped by Marszal et al. (2011) and the distinct alternatives mentioned or proposed by different authors.

1.4. ZEB definition used in this paper

Table 1 shows the current diversity of ZEB definitions. So in order to access the viability of ZEB in Brazil it is important to establish what is the definition used.

Sartori et al. (2011) have put forward the idea that ZEB definitions vary according to the energy policies. As such, there is no one single correct ideal ZEB definition. Each ZEB definition depends on the policies aims.

Thus before defining a ZEB it is important to define energy policy aims first. In this paper two aims are assumed. First, assist the transition to a renewable energy mix. Second, shelter the residential consumer from increases in the energy price. To achieve those aims this paper assumes a grid-connected building, with a local all year energy balance. The local balance is easier to implement and maximizes both energy efficiency and local renewable generation according to Torcellini et al. (2006). Source metrics for energy balance induce lower need for the search of energy efficiency measures and reliance of external renewable sources of energy to meet balance according to Torcellini et al. (2006).

It assumes a mostly electricity-powered building, including the domestic hot water (DHW) supplied through an electric shower. It also assumes that all the remaining energy needs of the building are met, that is, space cooling and heating, lighting and appliances and other electrical and electronic devises resulting from plug process. The only non electric energy source is gas for cooking. This exception is made since the overwhelming majority of Brazilian dwellings today use gas for cooking. This paper aims to access the viability of conversion of Brazilian single family housing to ZEB in the current conditions. Transition of cooking energy to an electric source, needs to happen but is a future step. It focuses only in the operational phase of the building. Energy consumed the construction and demolition phases of the life cycle are not considered in the balance. In relation to thermal performance, it requires that a ZEB reaches level A according to the Brazilian labeling scheme for

[1] The grid connection also allows for smaller thus more economical renewable generation systems. Since the building can rely on the utility grid, its generation needs to match only the annual net balance. Off grid buildings need to match their annual peak consumption and store extra energy for low generation periods, resulting in a more complex and expensive system that must include energy storage facilities coupled with higher generating capacity.

[2] Most authors of these papers are members of the IEA SHC Task40/ECBCS Annex52. Karsten Voss is member of the task force and an co-author in both papers as is Sartori (Marszal et al., 2011; Sartori et al., 2011)